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(54) **FAULT DETECTION FOR A SPEED SENSING SYSTEM OF A MULTI-ENGINE ROTORCRAFT**

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(51) **Int. Cl.**

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B64F 5/60	(2017.01)
B64C 27/06	(2006.01)
B64D 37/00	(2006.01)
G01P 3/00	(2006.01)

(52) **U.S. Cl.**
CPC ***B64D 31/06*** (2013.01); ***B64C 27/06*** (2013.01); ***B64D 37/00*** (2013.01); ***B64F 5/60*** (2017.01); ***G01P 3/00*** (2013.01)

(58) **Field of Classification Search**
CPC ... B64C 27/06; B64F 5/60; G01P 3/00; G01P 21/02
See application file for complete search history.

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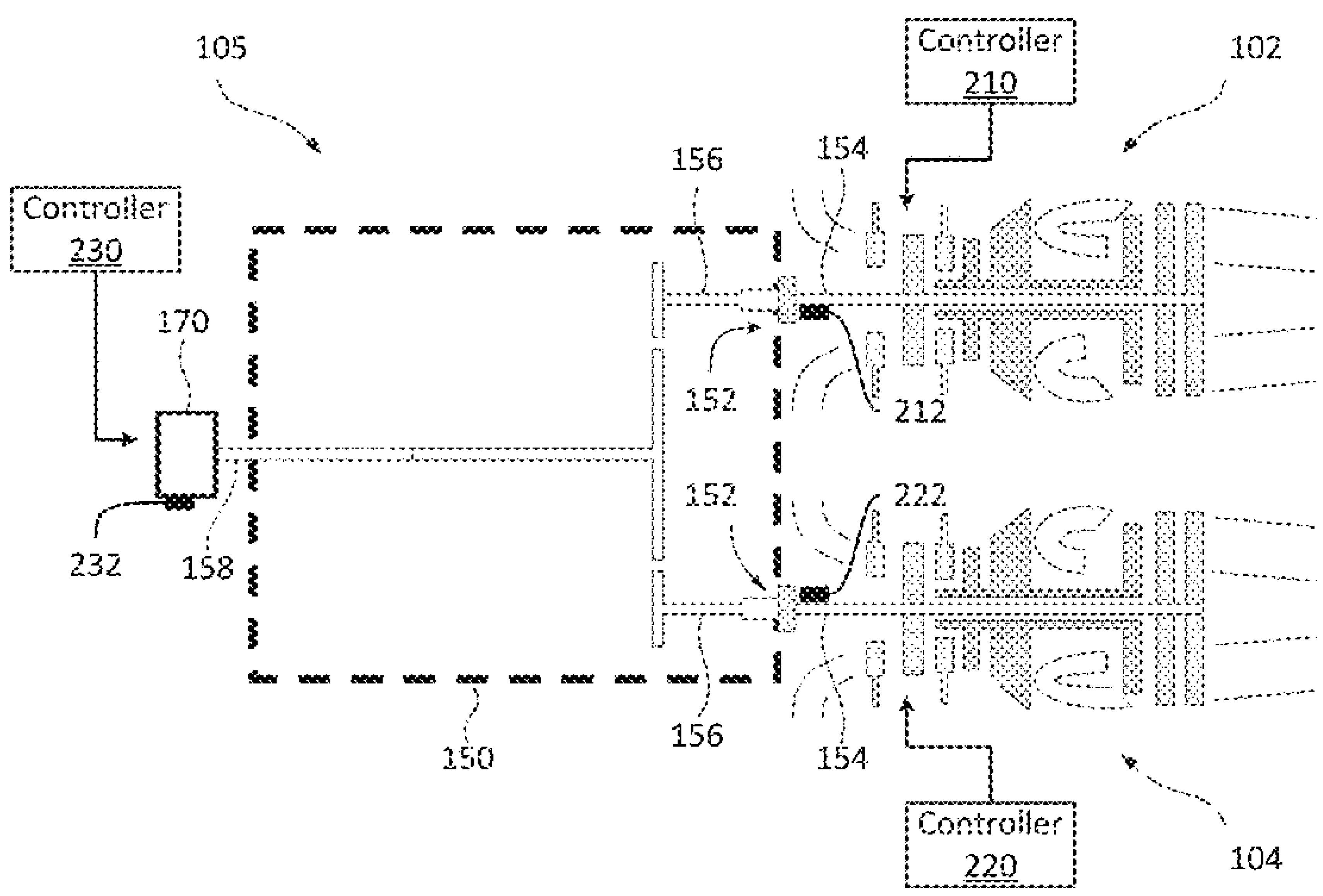
(57) **ABSTRACT**

The present disclosure provides methods and systems for fault detection for a speed sensing system of a multi-engine rotorcraft. A shaft speed for a first engine and a rotor speed for at least one rotor of the multi-engine rotorcraft are obtained. The shaft speed is compared to the rotor speed. When the shaft speed is greater than the rotor speed, a first fault in the speed sensing system is detected and a first speed sensing system fault signal is issued. When the shaft speed is less than the rotor speed, a determination is made regarding whether the first engine is coupled the at least one rotor based on a fuel flow to the first engine. A second fault in the speed sensing system is detected and a second speed sensing system fault signal is issued responsive to determining that the first engine is coupled to the at least one rotor.

20 Claims, 6 Drawing Sheets



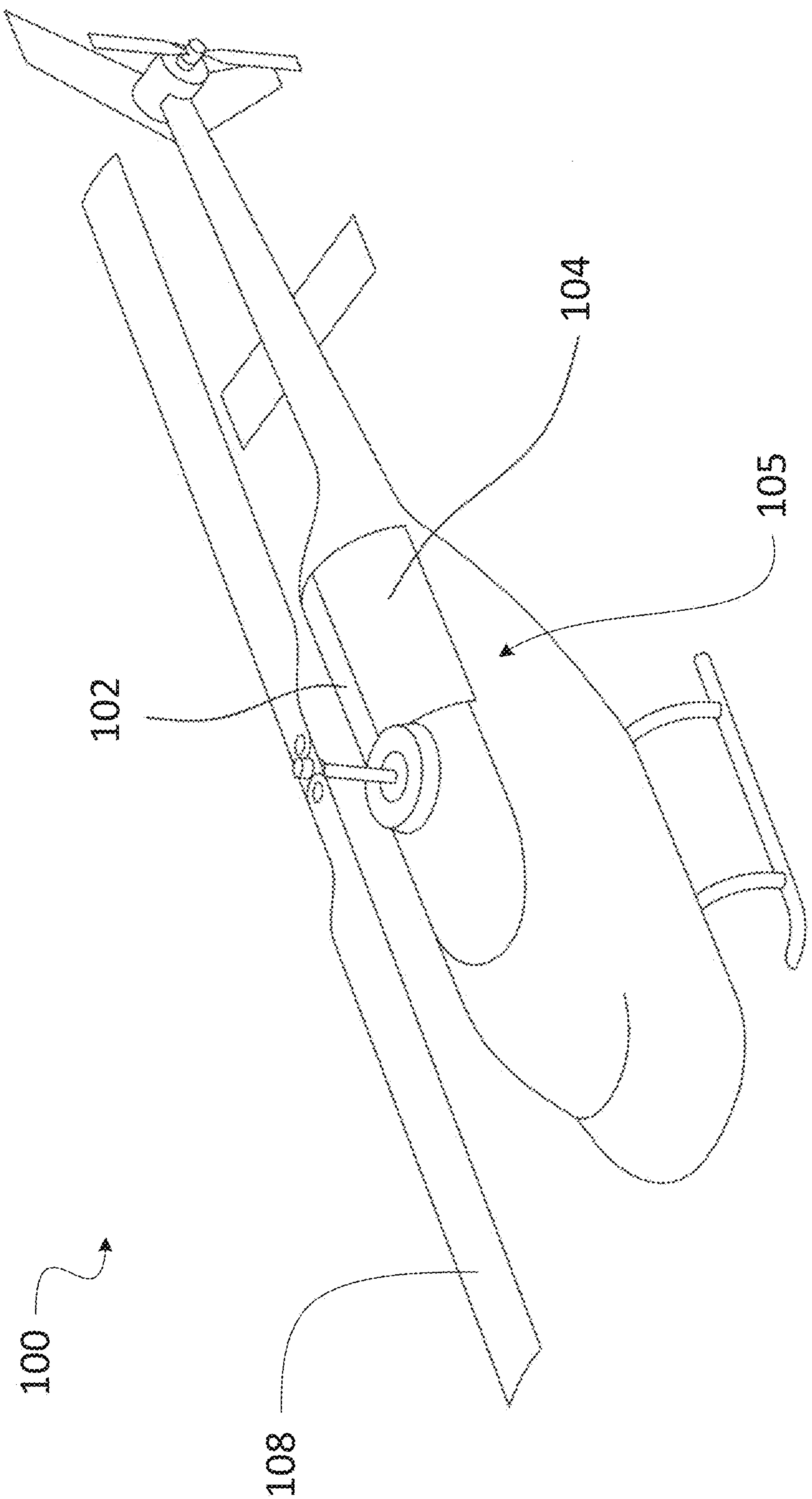


FIG. 1A

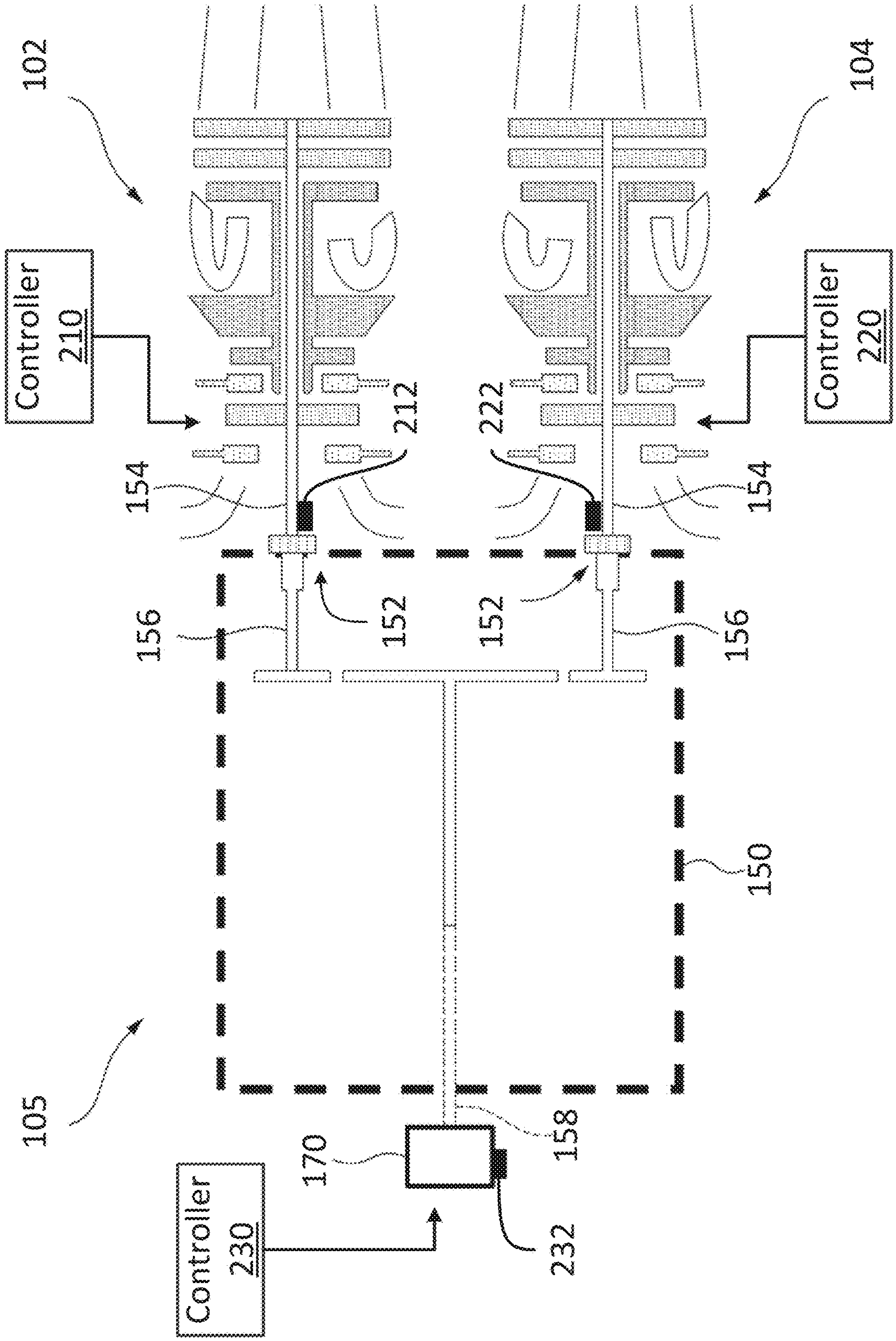

102
104
Controller
210
Controller
220
212
222
154
154
152
152
156
156
150
105
158
170
232
Controller
230

FIG. 1B

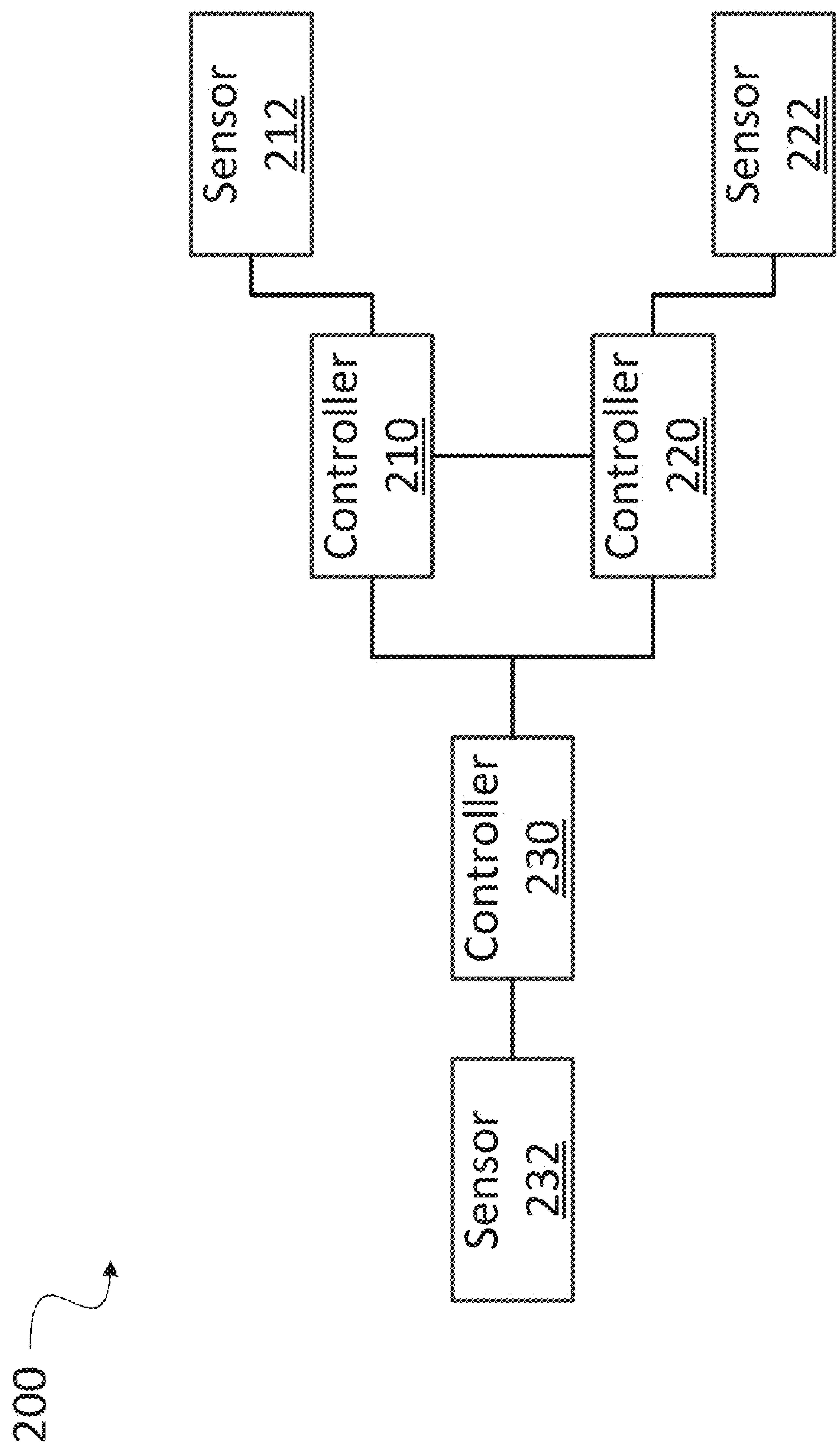

Sensor 212
Controller 210
Sensor 222
Controller 220
Controller 230
Sensor 232
200

FIG. 1C

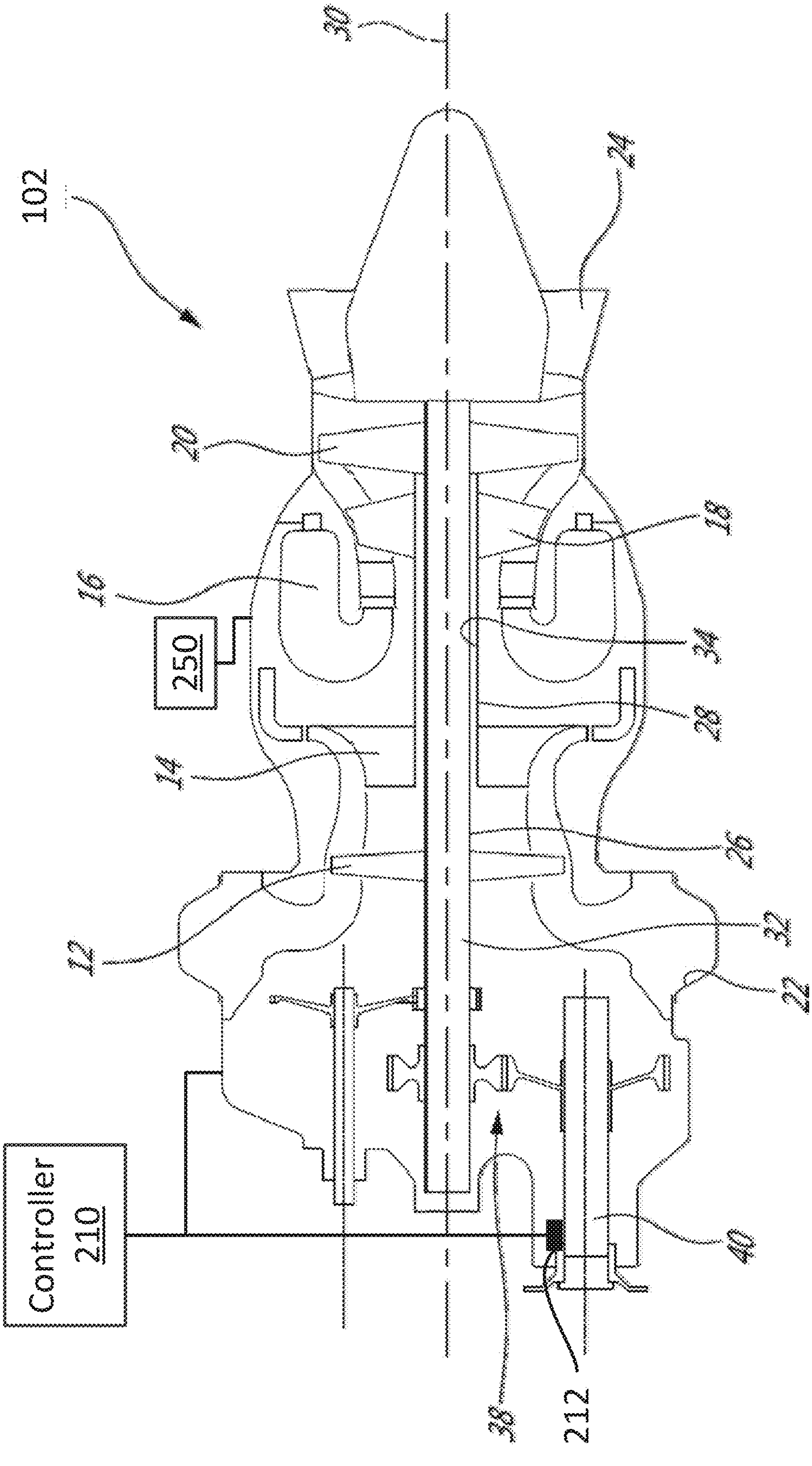

102
30
24
20
18
16
250
34
28
14
26
12
32
22
Controller
210
40
38
212

FIG. 2

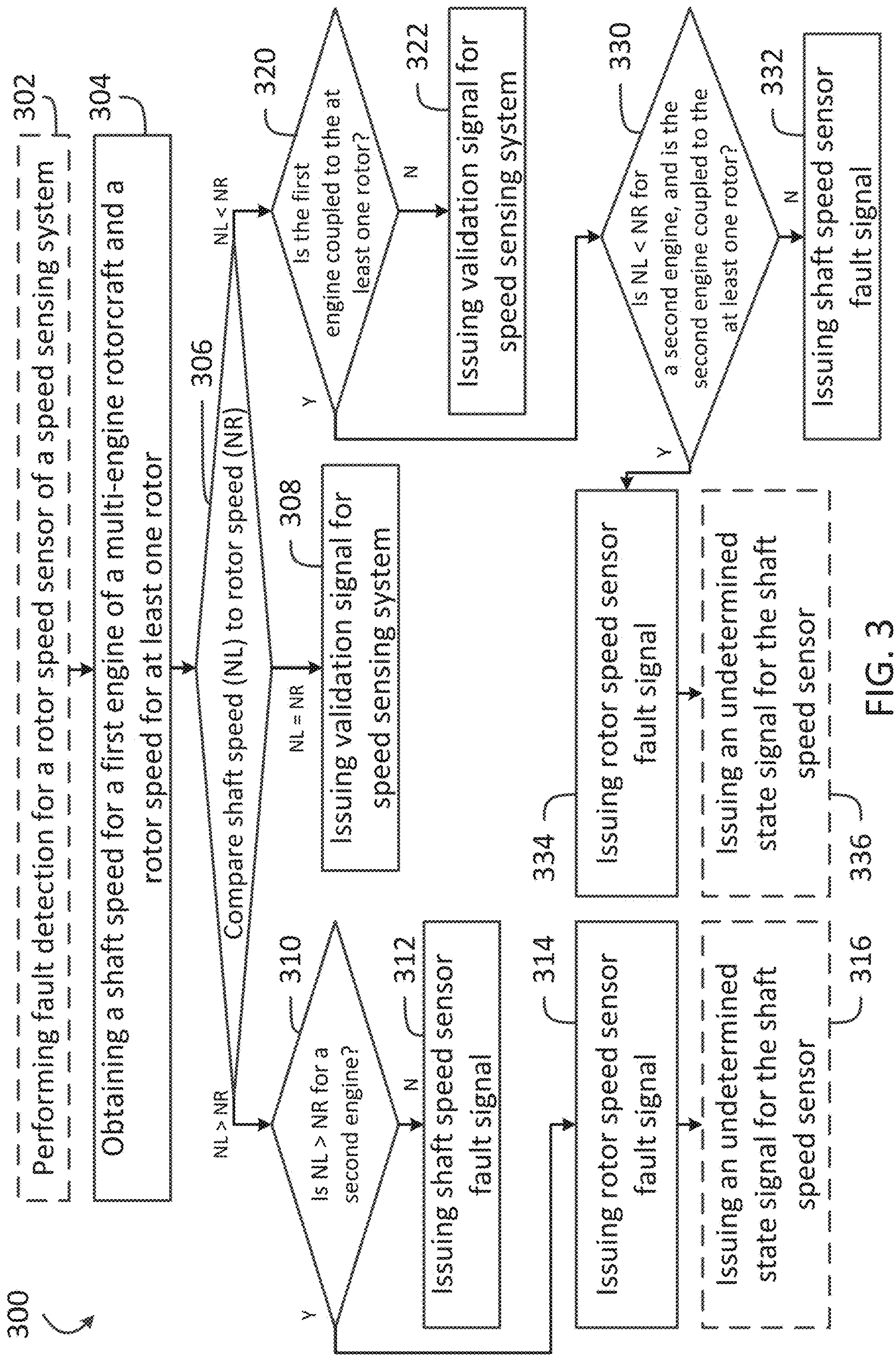

300
302
Performing fault detection for a rotor speed sensor of a speed sensing system
304
Obtaining a shaft speed for a first engine of a multi-engine rotorcraft and a rotor speed for at least one rotor
306
Compare shaft speed (NL) to rotor speed (NR)
NL < NR
NL = NR
NL > NR
308
Issuing validation signal for speed sensing system
310
Is NL > NR for a second engine?
Y
N
312
Issuing shaft speed sensor fault signal
314
Issuing rotor speed sensor fault signal
316
Issuing an undetermined state signal for the shaft speed sensor
320
Is the first engine coupled to the at least one rotor?
Y
N
322
Issuing validation signal for speed sensing system
330
Is NL < NR for a second engine, and is the second engine coupled to the at least one rotor?
Y
N
332
Issuing shaft speed sensor fault signal
334
Issuing rotor speed sensor fault signal
336
Issuing an undetermined state signal for the shaft speed sensor

FIG. 3

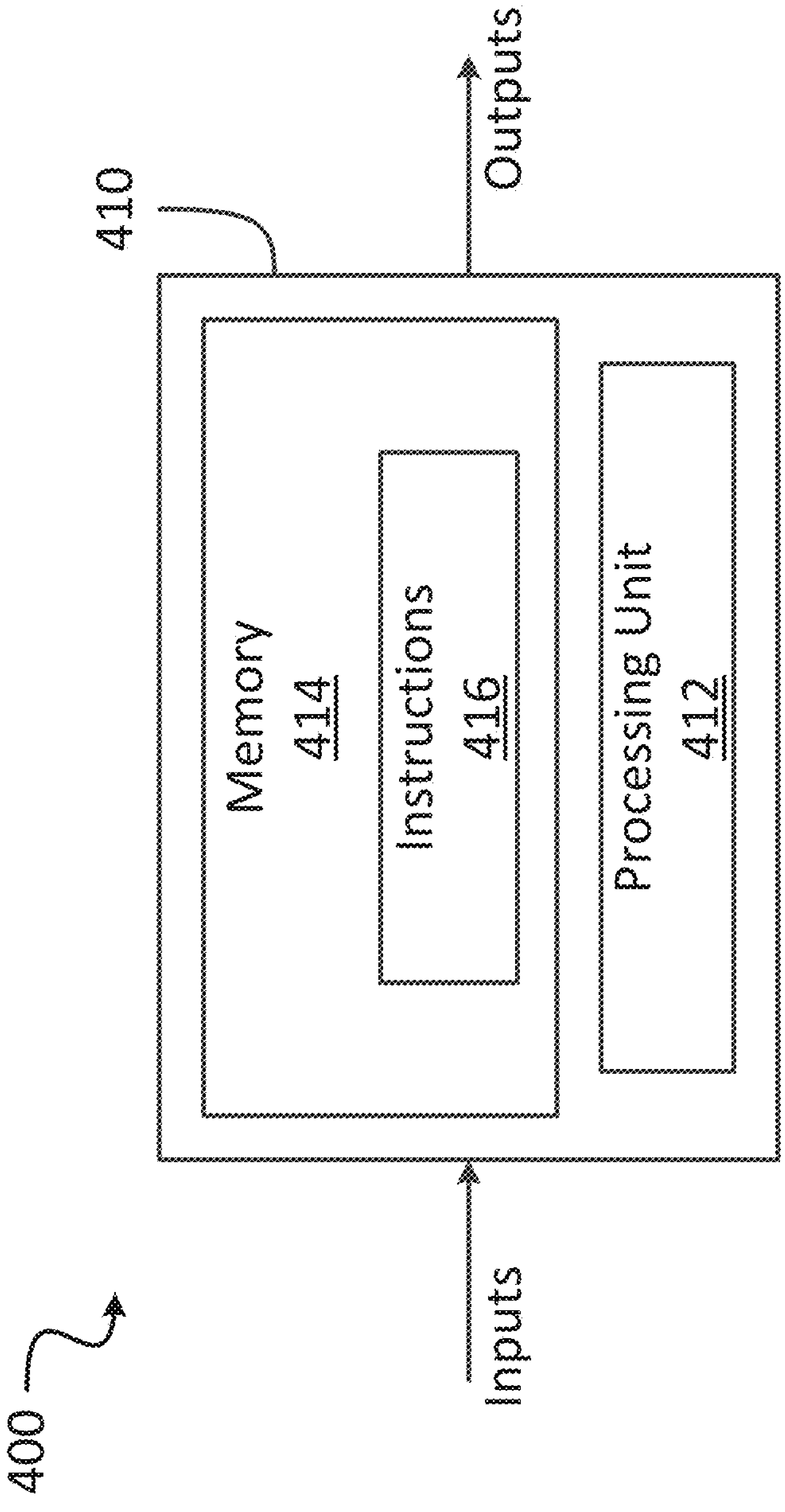

400
410
Outputs
Memory
414
Instructions
416
Processing Unit
412
Inputs

FIG. 4

FAULT DETECTION FOR A SPEED SENSING SYSTEM OF A MULTI-ENGINE ROTORCRAFT

TECHNICAL FIELD

The present disclosure relates generally to a multi-engine rotorcraft, and more particularly to a fault detection in multi-engine rotorcraft.

BACKGROUND OF THE ART

Multi-engine rotorcraft make use of speed signals from engines and rotors to control the operation of the rotorcraft. In some cases, the speed signals include an engine output shaft rotational speed and a rotor rotational speed. Although unlikely, fault events can occur for speed sensors. As a result, engine control systems are provided with functionality to assess whether speed sensors are experiencing a fault event.

While existing fault event detection approaches are suitable for their purposes, improvements remain desirable.

SUMMARY

In accordance with a broad aspect, there is provided a fault detection method for a speed sensing system of a multi-engine rotorcraft having at least one rotor. A shaft speed for a first engine of the multi-engine rotorcraft and a rotor speed for the at least one rotor are obtained. The shaft speed is compared to the rotor speed. When the shaft speed is greater than the rotor speed, a first fault in the speed sensing system is detected and a first speed sensing system fault signal is issued. When the shaft speed is less than the rotor speed, a determination is made regarding whether the first engine is coupled the at least one rotor based on a fuel flow to the first engine. A second fault in the speed sensing system is detected and a second speed sensing system fault signal is issued responsive to determining that the first engine is coupled to the at least one rotor.

In accordance with another broad aspect, there is provided a system for performing fault detection for a speed sensing system of a multi-engine rotorcraft having at least one rotor. The system comprises a processing unit, and a non-transitory computer-readable medium having stored thereon program instructions. The program instructions are executable by the processing unit for: obtaining a shaft speed for a first engine of the multi-engine rotorcraft and a rotor speed for the at least one rotor; comparing the shaft speed to the rotor speed; when the shaft speed is greater than the rotor speed, detecting a first fault in the speed sensing system and issuing a first speed sensing system fault signal; and when the shaft speed is less than the rotor speed: determining whether the first engine is coupled the at least one rotor based on a fuel flow to the first engine; and detecting a second fault in the speed sensing system and issuing a second speed sensing system fault signal responsive to determining that the first engine is coupled to the at least one rotor.

Features of the systems, devices, and methods described herein may be used in various combinations, in accordance with the embodiments described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is now made to the accompanying figures in which:

FIG. **1**A is a schematic view of a multi-engine rotorcraft;

FIG. **1**B is a schematic representation of an example multi-engine system for the rotorcraft of FIG. **1**A, showing axial cross-sectional views of two gas turbine engines;

FIG. **1**C is a block diagram of an example speed sensing system for the multi-engine rotorcraft of FIG. **1**A;

FIG. **2** is a cross-sectional view of an example turboshaft engine of the aircraft of FIG. **1**A;

FIG. **3** is a flowchart of an example fault detection method for a speed sensing system of a multi-engine rotorcraft having at least one rotor; and

FIG. **4** is a block diagram of an example computing device for implementing the method of FIG. **3**.

It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

DETAILED DESCRIPTION

There are described herein methods and systems for fault detection of a speed sensing system of a multi-engine rotorcraft having at least one rotor. FIG. **1**A depicts an example multi-engine rotorcraft **100**, which in this case is a helicopter. The rotorcraft **100** includes at least two gas turbine engines **102**, **104**. These two engines **102**, **104** may be interconnected, in the case of the depicted helicopter application, by a common gearbox to form a multi-engine system **105**, as shown in FIG. **1**B, which drives a main rotor **108**.

Turning now to FIG. **1**B, illustrated is an example multi-engine system **105** that may be used as a power plant for an aircraft, including but not limited to a rotorcraft such as the helicopter **100**. The multi-engine system **105** may include two or more gas turbine engines **102**, **104**. In the case of a helicopter application, these gas turbine engines **102**, **104** will be turboshaft engines. More particularly, the multi-engine system **105** of this embodiment includes first and second turboshaft engines **102**, **104** each having a respective transmission **152** interconnected by a common output gearbox **150** to drive a common load **170**. In one embodiment, the common load **170** may comprise a rotary wing of the rotorcraft **100**. For example, the common load **170** may be a main rotor **108** of the aircraft **100**. Depending on the type of the common load **170** and on the operating speed thereof, each of turboshaft engines **102**, **104** may be drivingly coupled to the common load **170** via the output gearbox **150**, which may be a speed-reduction type gearbox.

For example, the gearbox **150** may have a plurality of transmission shafts **156** to receive mechanical energy from respective output shafts **154** of respective turboshaft engines **102**, **104**. The gearbox **150** may be configured to direct at least some of the combined mechanical energy from the plurality of the turboshaft engines **102**, **104** toward a common output shaft **158** for driving the common load **170** at a suitable operating (e.g., rotational) speed. It is understood that the multi-engine system **105** may also be configured, for example, to drive accessories and/or other elements of an associated aircraft. The gearbox **150** may be configured to permit the common load **170** to be driven by either of the turboshaft engines **102**, **104** or, by a combination of both engines **102**, **104** together.

Control of the multi-engine system **105** is effected by one or more controller(s), illustrated in FIG. **1**B as controllers **210**, **220**, and **230**, which are each associated with a particular component of the multi-engine system **105**: the controller **210** is associated with the engine **102**, the controller **220** is associated with the engine **104**, and the controller **230** is associated with the common load **170**. In some embodiments, the controllers **210**, **220**, **230** are

FADEC(s), electronic engine controller(s) (EEC(s)), or the like, that are programmed to control the operation of the engines **102**, **104** and the common load **170**. In some embodiments, the operation of the engines **102**, **104**, and of the rotor **108** is controlled by way of one or more actuators, mechanical linkages, hydraulic systems, and the like. The controller **210** can be coupled to the actuators, mechanical linkages, hydraulic systems, and the like, in any suitable fashion for effecting control of the engines **102**, **104** and/or of the rotor **108**. For example, if a change in the operating conditions of the aircraft **100** is detected without any corresponding change in inputs from an operator of the aircraft **100**, the FADEC can adjust the inputs to compensate for the uncommanded change.

With continued reference to FIG. **1**B and additional reference to FIG. **10**, the multi-engine system **105** also includes a number of speed sensors, illustrated as sensors **212**, **222**, **232**. Together, the controllers **210**, **220**, **230** and the sensors **212**, **222**, **232** form a speed sensing system **200** for the rotorcraft **100**. The sensors **212**, **222**, **232** are each associated with a particular mechanical component of the multi-engine system **105**, and serve to measure the rotational speed of the associated mechanical component. In the example illustrated in FIG. **1**B, the sensors **212** and **222** are coupled to the output shafts **154** of the engines **102**, **104**, respectively, and are configured for measuring a rotational speed of their respective output shaft **154**. The sensor **232** is coupled to the common load **170**, and is configured for measuring a rotational speed of one or more elements of the common load **170**, for instance the rotor **108**, or the common output shaft **158**. The speed sensing system **200** can thus monitor the rotational speed of the output shafts **154** and **158** and control the operation of the multi-engine system **105** based thereon.

It should be noted that although the present discussion focuses primarily on the inclusion of speed sensors in the form of sensors **212**, **222**, **232**, the multi-engine system **105** and the rotorcraft **100** can additionally include any number of sensors, including fuel flow sensors, temperature sensors, pressure sensors, and the like. In addition, the controller **210**, **220**, **230** can monitor any suitable number of other parameters, and can control the elements of the multi-engine system **105** in any other suitable fashion. It should be noted that in some embodiments, the controllers **210**, **220** can be embodied as a single unified engine controller, which is coupled to both engines **102**, **104**, and to the sensors **212**, **222**. In embodiments in which the multi-engine rotorcraft **100** includes more than two engines, a single unified engine controller can be used for all engines of the rotorcraft **100**, one or more unified engine controllers can be assigned to groups of engines, or single-engine controllers can be provided for each of the engines of the rotorcraft **100**.

With reference to FIG. **2**, the turboshaft engines **102**, **104** can be embodied as gas turbine engines. Although the foregoing discussion relates to engine **102**, it should be understood that engine **104** can be substantively similar to engine **102**. In this example, the engine **102** is a turboshaft engine generally comprising in serial flow communication a low pressure (LP) compressor section **12** and a high pressure (HP) compressor section **14** for pressurizing air, a combustor **16** in which the compressed air is mixed with fuel and ignited for generating an annular stream of hot combustion gases, a high pressure turbine section **18** for extracting energy from the combustion gases and driving the high pressure compressor section **14**, and a lower pressure turbine section **20** for further extracting energy from the combustion gases and driving at least the low pressure compressor section **12**. The engine **102** is provided with fuel via a fuel source **250**, which can be coupled to the engine **102** in any suitable fashion. Control of the flow of fuel to the engine **102** can be effected by the controller **210**, by a controller associated with the fuel source **250**, or by any other suitable controller.

The low pressure compressor section **12** may independently rotate from the high pressure compressor section **14**. The low pressure compressor section **12** may include one or more compression stages and the high pressure compressor section **14** may include one or more compression stages. A compressor stage may include a compressor rotor, or a combination of the compressor rotor and a compressor stator assembly. In a multistage compressor configuration, the compressor stator assemblies may direct the air from one compressor rotor to the next.

The engine **102** has multiple, i.e. two or more, spools which may perform the compression to pressurize the air received through an air inlet **22**, and which extract energy from the combustion gases before they exit via an exhaust outlet **24**. In the illustrated embodiment, the engine **102** includes a low pressure spool **26** and a high pressure spool **28** mounted for rotation about an engine axis **30**. The low pressure and high pressure spools **26**, **28** are independently rotatable relative to each other about the axis **30**. The term "spool" is herein intended to broadly refer to drivingly connected turbine and compressor rotors.

The low pressure spool **26** includes a low pressure shaft **32** interconnecting the low pressure turbine section **20** with the low pressure compressor section **12** to drive rotors of the low pressure compressor section **12**. In other words, the low pressure compressor section **12** may include at least one low pressure compressor rotor directly drivingly engaged to the low pressure shaft **32** and the low pressure turbine section **20** may include at least one low pressure turbine rotor directly drivingly engaged to the low pressure shaft **32** so as to rotate the low pressure compressor section **12** at a same speed as the low pressure turbine section **20**. The high pressure spool **28** includes a high pressure shaft **34** interconnecting the high pressure turbine section **18** with the high pressure compressor section **14** to drive rotors of the high pressure compressor section **14**. In other words, the high pressure compressor section **14** may include at least one high pressure compressor rotor directly drivingly engaged to the high pressure shaft **34** and the high pressure turbine section **18** may include at least one high pressure turbine rotor directly drivingly engaged to the high pressure shaft **34** so as to rotate the high pressure compressor section **14** at a same speed as the high pressure turbine section **18**. In some embodiments, the high pressure shaft **34** may be hollow and the low pressure shaft **32** extends therethrough. The two shafts **32**, **34** are free to rotate independently from one another. The engine **102** may include a transmission **38** driven by the low pressure shaft **32** and driving a rotatable output shaft **40**. The transmission **38** may vary a ratio between rotational speeds of the low pressure shaft **32** and the output shaft **40**.

As described hereinabove, control of the operation of the engine **102** can be effected by one or more control systems, for example the controller **210**, which forms part of the speed sensing system **200**, along with the sensor **212**. The controller **210** can modulate a fuel flow rate provided to the engine **102**, the position and/or orientation of variable geometry mechanisms within the engine **102**, a bleed level of the engine **102**, and the like, based on readings provided by the sensor **212**, or based readings provided by other sensors within, or in the periphery of, the engine **102**.

In some cases, it can occur that one or more of the sensors **212**, **222**, **232** experiences a fault event. A fault event for one of the sensors **212**, **222**, **232** occurs when the speed readings provided by the particular sensor are not representative of an actual rotational speed for the output shaft to which the particular sensor is associated. For instance, when the sensor **212** experiences a fault event, the speed readings provided by the sensor **212** are no longer representative of the actual rotational speed of the output shaft **154** of the engine **102**. A fault event can occur for a number of reasons, including failure of the sensor **212**, dissociation of the sensor **212** from the output shaft **154**, the presence of debris or other interfering materials affecting the readings provided by the sensor **212**, faulty connection between the sensor **212** and the controller **210**, or for any other number of reasons. In some situations, the controller **210** to which the sensor **212** is coupled may not be able to detect the occurrence of the fault event based on the values provided by the sensor **212** itself. That is to say, the values provided by the sensor **212** may appear accurate to the controller **210**, but may in fact be erroneous.

With continued reference to FIG. **10**, and additional reference to FIG. **3**, there is illustrated a flowchart describing a fault detection method **300** which can serve to detect the occurrence for fault events for one or more of the sensors **212**, **222**, **232** of the speed sensing system **200**. As will be described in greater detail hereinbelow, the fault detection method **300** obtains readings from the sensors **212**, **222**, **232** and performs comparisons therebetween in order to assess whether any of the sensors **212**, **222**, **232** have experienced a fault event.

Optionally, at step **302**, fault detection for a rotor speed sensor, for instance the sensor **232** of the speed sensing system **200**, is performed. Fault detection for the sensor **232** can be performed by comparing rotor speed readings obtained by the controllers **210**, **220** from the controller **230** or from the sensor **232**. For example, the controller **230** obtains rotor speed readings from the sensor **232**, and provides the rotor speed readings to the controllers **210**, **220**. The controllers **210**, **220** can exchange their received rotor speed readings to assess the validity of the sensor **232**. If the rotor speed readings received by the controllers **210**, **220** differ beyond a predetermined threshold, it can be concluded that the sensor **232** is experiencing a fault event. In some embodiments, the exchange of the rotor speed readings may be unidirectional: for instance, the controller **220** provides the controller **210** with the received rotor speed readings, and the controller **210** performs the comparison to determine whether the sensor **232** is experiencing a fault event. When a fault event for the sensor **232** is detected, the controller **210** informs the controller **220** of the fault event, and both controllers **210**, **220** can take appropriate countermeasures.

As noted above, step **302** is optional. In some cases, step **302** is omitted because an assessment of whether the sensor **232** is experiencing a fault event can be detected in other ways, as discussed hereinbelow. In other cases, step **302** is omitted because the controllers **210**, **220** are implemented via a single unified engine controller, and the unified engine controller receives only one input from the sensor **232**, whether via the controller **230** or otherwise.

At step **304**, a shaft speed for a first engine and a rotor speed for at least one rotor are obtained, for instance a shaft speed for the output shaft **154** of the engine **102**, and a rotor speed for the rotor **108** forming part of the common load **170**. The shaft speed can be obtained from the sensor **212**, and the rotor speed can be obtained from the sensor **232**, for instance via the controller **230**; both the shaft speed and the rotor speed can be obtained at the controller **210**, although it is considered that the same steps can be implemented by the controller **220**, for instance using the shaft speed for the output shaft **154** of the engine **104**, supplied by the sensor **222**.

At decision step **306**, a comparison is made between the shaft speed and the rotor speed. Depending on the result of the comparison, the method **300** proceeds to one of three subsequent steps. When the shaft speed and rotor speed are equal, or equal to within a tolerance or range, the method **300** proceeds to step **308**. When the shaft speed is greater than the rotor speed, or above than the rotor speed by a predetermined amount or percentage, the method **300** proceeds to step **310**. When the shaft speed is less than the rotor speed, or below the rotor speed by a predetermined amount or percentage, the method **300** proceeds to step **320**.

The tolerance or ranges for the comparisons performed at step **306** can be predetermined based on a number of factors, including the model of the engines **102**, **104**, the model of the rotor **108**, the mechanical coupling between the engines **102**, **104** and the common load **170** provided by the gearbox **150**, or any other suitable characteristics. In some cases, the tolerances or ranges can also be adjusted based on any number of operating parameters for the engines **102**, **104**, and/or the rotor **108**, for instance a flight stage for the rotorcraft **100**, an altitude or temperature of operation for the rotorcraft **100**, or the like.

When the shaft speed and the rotor speed are equal, or equal within a predetermined tolerance or range, the method **300** moves from step **306** to step **308**. At step **308**, a validation signal for the speed sensing system **200** is issued. In some embodiments, the validation signal can be associated with the sensor **212**, and can indicate that the readings provided by the sensor **212** have been validated. The validation of the sensor **212** can be for a predetermined time, or can be indicated as validated until the method **300** is repeated, as appropriate. In some other embodiments, when the shaft speed and the rotor speed are equal, or equal to within a predetermined tolerance, the method **300** can simply end, or return to a previous step (for instance step **302** or step **304**), and no explicit validation signal is issued. In these embodiments, the sensors **212**, **222**, **232** can be considered validated unless indicated as faulty.

When the shaft speed is greater than the rotor speed, the method **300** moves to step **310**. It should be noted that, because of the mechanical coupling between the output shafts **154** and the rotor **108**—via the gearbox **150**—situations in which the shaft speed is higher than the rotor speed do not occur under normal operating conditions. As a result, when the comparison at step **306** determines that the shaft speed is greater than the rotor speed, a fault is detected in the speed sensing system **200**, and a fault signal is issued for the speed sensing system **200**, as discussed hereinbelow.

At decision step **310**, the rotor speed is compared to a corresponding shaft speed of a second engine of the rotorcraft **100**. In this example, the rotor speed obtained from the sensor **232**, for instance via the controller **230**, is compared to the shaft speed provided by the sensor **212** for the engine **102** at step **306**; at step **308**, the rotor speed is compared to the corresponding shaft speed for the engine **104**, which is provided by the sensor **222**, and which can be obtained via the controller **220**. When the corresponding shaft speed is greater than the rotor speed, the method **300** moves to step **314**. When the corresponding shaft speed is not greater than the rotor speed, the method **300** moves to step **312**.

In the case where the comparison of the corresponding shaft speed and the rotor speed indicates that the corresponding shaft speed is not greater than the rotor speed, the method **300** moves from decision step **310** to step **312**. At step **312**, a shaft speed sensor fault signal is issued, which indicates that the shaft speed sensor which provided the shaft speed for the engine **102**, in this case the sensor **212**, is faulty. In this case, because the shaft speed was found to be greater than the rotor speed at decision step **306**—an outcome which does not occur under normal operating conditions—but the corresponding shaft speed for the engine **104** was not found to be greater than the rotor speed at decision step **310**, it is concluded that the sensor **212** which reports the shaft speed is faulty. As a result, a fault signal which indicates that the sensor **212** is faulty is issued.

In the case where the comparison of the corresponding shaft speed and the rotor speed indicates that the corresponding shaft speed is also greater than the rotor speed, the method **300** moves from decision step **310** to step **314**. At step **314**, a rotor speed sensor fault signal is issued, which indicates that the rotor speed sensor which provided the rotor speed for the rotor **108**, in this case the sensor **232**, is faulty. In this case, because the both the shaft speed and the corresponding shaft speed were found to be greater than the rotor speed at decision steps **306** and **310**—outcomes which do not occur under normal operating conditions—it is concluded that the sensor **232** which reports the rotor speed is faulty. As a result, a fault signal which indicates that the sensor **232** is faulty is issued.

Optionally, the method **300** moves from step **314** to step **316**. At optional step **316**, an undetermined state signal is issued for the shaft speed sensor, in this case sensor **212**. Because the results of the comparisons at decision steps **306** and **310** indicate that the sensor **232** is faulty, the validity of the sensor **212** is unknown. As a result, an undetermined state signal can be issued to assign an undetermined state to the sensor **212**.

When the shaft speed is less than the rotor speed, the method **300** moves to step **320**. It should be noted that, because of the mechanical coupling between the output shafts **154** and the rotor **108**—via the gearbox **150**—situations in which the shaft speed is lower than the rotor speed can occur when the engine **102** is decoupled from the rotor **108**. As a result, when the comparison at step **306** determines that the shaft speed is less than the rotor speed, the method **300** moves to step **320**.

At decision step **320**, a determination is made regarding whether the engine **102** is coupled to the rotor **108**. In some embodiments, the determination is made based on a fuel flow to the engine **102**, for instance as provided by the fuel source **250**. For example, the fuel flow to the engine **102** is compared to a predetermined fuel flow threshold: when the fuel flow is above the threshold, the engine **102** is determined to be coupled to the rotor **108** (i.e., not decoupled), and when the fuel flow is below the threshold, the engine **102** is determined to be decoupled from the rotor **108**. When the engine **102** is determined to be coupled to the rotor **108**, the method **300** moves to step **330**. When the engine **102** is determined to be decoupled from the rotor **108**, the method **300** moves to step **322**.

In some embodiments, the fuel flow to the engine **102** can be adjusted based on one or more operating conditions for the engine **102**, for instance an ambient temperature or an ambient pressure of the environment in which the engine **102** is operating. The adjusted fuel flow is then compared to the threshold, and the engine **102** is determined to be coupled or decoupled based on the comparison. In some other embodiments, the threshold can be adjusted based on the one or more operating conditions for the engine **102**, or can be determined dynamically based on any suitable parameters. It should also be noted that other approaches for assessing whether the engine **102** is decoupled from the rotor **108** are considered. For instance, a compressor pressure for the engine **102** and/or an exhaust gas temperature for the engine **102** can be compared to relevant thresholds to assess whether the engine **102** is decoupled from the rotor **108**.

In the case where it is determined that the engine **102** is decoupled, the method **300** moves from decision step **320** to step **322**. At step **322**, a validation signal for the speed sensing system **200** is issued. In some embodiments, the validation signal can be associated with the sensor **212**, and can indicate that the readings provided by the sensor **212** have been validated. The validation of the sensor **212** can be for a predetermined time, or can be indicated as validated until the method **300** is repeated, as appropriate. In some other embodiments, when it is determined that the engine **102** is decoupled from the rotor **108**, the method **300** can simply end, or return to a previous step (for instance step **302** or step **304**), and no explicit validation signal is issued. In these embodiments, the sensors **212**, **222**, **232** can be considered validated unless indicated as faulty.

In the case where it is determined that the engine **102** is coupled, the method **300** moves from decision step **320** to decision step **330**. At decision step **330**, the rotor speed is compared to the corresponding shaft speed of the engine **104**, which is provided by the sensor **222**, and which can be obtained via the controller **220**. Additionally, a determination is made regarding whether the engine **104** is coupled to the rotor **108**. When the corresponding shaft speed is less than the rotor speed, and when the second engine is determined to be coupled, the method **300** moves to step **334**. When either the corresponding shaft speed is not less than the rotor speed, or when the second engine is not determined to be coupled, the method **300** moves to step **332**.

In the case where the corresponding shaft speed is not less than the rotor speed, and when the second engine is determined to be coupled, the method **300** moves from decision step **330** to step **332**. At step **332**, a shaft speed sensor fault signal is issued, which indicates that the shaft speed sensor which provided the shaft speed for the engine **102**, in this case the sensor **212**, is faulty. In this case, because the shaft speed was found to be less than the rotor speed while the engine **102** to the rotor **108**, and because a similar set of conditions was not identified for the engine **104**, it is concluded that the sensor **212** which reports the shaft speed is faulty. As a result, a fault signal which indicates that the sensor **212** is faulty is issued.

In the case where the corresponding shaft speed is less than the rotor speed, and when the engine **104** is determined to be coupled to the rotor **108**, the method **300** moves from decision step **330** to step **334**. At step **334**, a rotor speed sensor fault signal is issued, which indicates that the rotor speed sensor which provided the rotor speed for the rotor **108**, in this case the sensor **232**, is faulty. In this case, because the both the shaft speed and the corresponding shaft speed were found to be less than the rotor speed at decision steps **306** and **330** while engines **102** and **104** were determined as being coupled to the rotor **108** at decision steps **320** and **330**, it is concluded that the sensor **232** which reports the rotor speed is faulty. As a result, a fault signal which indicates that the sensor **232** is faulty is issued.

Optionally, the method **300** moves from step **334** to step **336**. At optional step **336**, an undetermined state signal is issued for the shaft speed sensor, in this case sensor **212**. Because the results of the comparisons at decision steps **306**, 320, and 330 indicate that the sensor 232 is faulty, the validity of the sensor 212 is unknown. As a result, an undetermined state signal can be issued to assign an undetermined state to the sensor 212.

Because of the established mechanical coupling between the output shafts 154 and the common output shaft 158, the results of comparisons between the shaft speed for the engine 102, the rotor speed for the rotor 108, and optionally the shaft speed for the engine 104, can be used to perform fault detection for the speed sensing system 200, including the sensors 212, 222, 232. In some embodiments, the method 300, when implemented within an engine controller, for instance the controllers 210, 220, can reduce or eliminate the need for sensor redundancy within the engines 102, 104 and/or within the common load 170. That is to say, in some embodiments, the sensors 212, 222, 232 can be single sensors, without any redundancy, allowing for reduced cost and/or weight requirements for the engine 102, 104, and for the rotorcraft 100. It should be noted that although the foregoing description of the method 300 was provided from the perspective of the controller 210, the controller 220 can also implement the method 300, for instance concurrently with the implementation of the method 300 by the controller 210. From the perspective of the controller 220, the corresponding shaft speed is the shaft speed provided by the sensor 212, which can be obtained via the controller 210.

With reference to FIG. 4, the method 300 may be implemented by a computing device 410, which can embody part or all of the speed sensing system 200, for instance the controller 210 and/or the controller 220. The computing device 410 comprises a processing unit 412 and a memory 414 which has stored therein computer-executable instructions 416. The processing unit 412 may comprise any suitable devices configured to implement the functionality of the speed sensing system 200 and/or the functionality described in the method 300, such that instructions 416, when executed by the computing device 410 or other programmable apparatus, may cause the functions/acts/steps performed by the speed sensing system 200 and/or described in the method 300 as provided herein to be executed. The processing unit 412 may comprise, for example, any type of general-purpose microprocessor or microcontroller, a digital signal processing (DSP) processor, a central processing unit (CPU), an integrated circuit, a field programmable gate array (FPGA), a reconfigurable processor, other suitably programmed or programmable logic circuits, custom-designed analog and/or digital circuits, or any combination thereof.

The memory 414 may comprise any suitable known or other machine-readable storage medium. The memory 414 may comprise non-transitory computer readable storage medium, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. The memory 414 may include a suitable combination of any type of computer memory that is located either internally or externally to device, for example random-access memory (RAM), read-only memory (ROM), compact disc read-only memory (CDROM), electro-optical memory, magneto-optical memory, erasable programmable read-only memory (EPROM), and electrically-erasable programmable read-only memory (EEPROM), Ferroelectric RAM (FRAM) or the like. Memory 414 may comprise any storage means (e.g., devices) suitable for retrievably storing machine-readable instructions 416 executable by processing unit 412.

The embodiments described in this document provide non-limiting examples of possible implementations of the present technology. Upon review of the present disclosure, a person of ordinary skill in the art will recognize that changes may be made to the embodiments described herein without departing from the scope of the present technology. Yet further modifications could be implemented by a person of ordinary skill in the art in view of the present disclosure, which modifications would be within the scope of the present technology.

The invention claimed is:

1. A fault detection method for a speed sensing system of a multi-engine rotorcraft having at least one rotor, the method comprising:
 obtaining a shaft speed for a first engine of the multi-engine rotorcraft and a rotor speed for the at least one rotor;
 comparing the shaft speed to the rotor speed;
 when the shaft speed is greater than the rotor speed, detecting a first fault in the speed sensing system and issuing a first speed sensing system fault signal; and
 when the shaft speed is less than the rotor speed:
 determining whether the first engine is coupled to the at least one rotor based on a fuel flow to the first engine;
 detecting a second fault in the speed sensing system and issuing a second speed sensing system fault signal responsive to determining that the first engine is coupled to the at least one rotor; and
 controlling the multi-engine rotorcraft according to the first speed sensing system fault signal or the second speed sensing system fault signal.

2. The method of claim 1, wherein detecting the second fault comprises determining whether a second engine of the multi-engine rotorcraft is coupled to the at least one rotor based on a corresponding fuel flow for the second engine, and wherein issuing the second speed sensing system fault signal comprises issuing a shaft speed sensor fault signal responsive to detecting a shaft speed sensor fault in the speed sensing system when the second engine is decoupled from the at least one rotor.

3. The method of claim 2, wherein issuing the second speed sensing system fault signal comprises issuing a rotor speed sensor fault signal responsive to detecting a rotor speed sensor fault in the speed sensing system when the second engine is coupled to the at least one rotor.

4. The method of claim 3, wherein issuing the second speed sensing system fault comprises issuing an undetermined state signal to assign an undetermined validity state to the shaft speed sensor.

5. The method of claim 1, wherein detecting the first fault comprises comparing the rotor speed to a corresponding shaft speed of a second engine of the multi-engine rotorcraft, and wherein issuing the first speed sensing system fault signal comprises issuing a shaft speed sensor fault responsive to detecting a shaft speed sensor fault in the speed sensing system when the corresponding shaft speed is not greater than the rotor speed.

6. The method of claim 5, wherein issuing the first speed sensing system fault signal comprises issuing a rotor speed sensor fault signal responsive to detecting a rotor speed sensor fault in the speed sensing system when the corresponding shaft speed is greater than the rotor speed.

7. The method of claim 6, wherein issuing the first speed sensing system fault comprises issuing an undetermined state signal to assign an undetermined validity state to the shaft speed sensor.

8. The method of claim 1, wherein the rotor speed is obtained by a first controller associated with the first engine, the method further comprising:

obtaining a corresponding rotor speed via a second controller associated with a second engine of the multi engine rotorcraft;

comparing the rotor speed to the corresponding rotor speed; and

issuing a rotor speed sensor fault signal responsive to determining that the rotor speed and the corresponding rotor speed differ beyond a predetermined rotor speed threshold.

9. The method of claim **1**, wherein determining whether the first engine is coupled to the at least one rotor based on the fuel flow to the first engine comprises:

adjusting the fuel flow to the first engine based on at least one ambient condition to the first engine; and

comparing the adjusted fuel flow to a predetermined fuel flow threshold;

wherein the first engine is determined to be decoupled from the at least one rotor when the adjusted fuel flow is below the predetermined fuel threshold.

10. The method of claim **1**, wherein comparing the shaft speed to the rotor speed comprises applying a scaling factor to one of the shaft speed and the rotor speed, the scaling factor based on a mechanical coupling between the first engine and the at least one rotor.

11. A system for performing fault detection for a speed sensing system of a multi-engine rotorcraft having at least one rotor, the system comprising:

a processing unit; and

a non-transitory computer-readable medium having stored thereon program instructions executable by the processing unit for:

obtaining a shaft speed for a first engine of the multi-engine rotorcraft and a rotor speed for the at least one rotor;

comparing the shaft speed to the rotor speed;

when the shaft speed is greater than the rotor speed, detecting a first fault in the speed sensing system and issuing a first speed sensing system fault signal; and

when the shaft speed is less than the rotor speed:

determining whether the first engine is coupled to the at least one rotor based on a fuel flow to the first engine;

detecting a second fault in the speed sensing system and issuing a second speed sensing system fault signal responsive to determining that the first engine is coupled to the at least one rotor; and

controlling the multi-engine rotorcraft according to the first speed sensing system fault signal or the second speed sensing system fault signal.

12. The system of claim **11**, wherein detecting the second fault comprises determining whether a second engine of the multi-engine rotorcraft is coupled to the at least one rotor based on a corresponding fuel flow for the second engine, and wherein issuing the second speed sensing system fault signal comprises issuing a shaft speed sensor fault signal responsive to detecting a shaft speed sensor fault in the speed sensing system when the second engine is decoupled from the at least one rotor.

13. The system of claim **12**, wherein issuing the second speed sensing system fault signal comprises issuing a rotor speed sensor fault signal responsive to detecting a rotor speed sensor fault in the speed sensing system when the second engine is coupled to the at least one rotor.

14. The system of claim **13**, wherein issuing the second speed sensing system fault comprises issuing an undetermined state signal to assign an undetermined validity state to the shaft speed sensor.

15. The system of claim **11**, wherein detecting the first fault comprises comparing the rotor speed to a corresponding shaft speed of a second engine of the multi-engine rotorcraft, and wherein issuing the first speed sensing system fault signal comprises issuing a shaft speed sensor fault responsive to detecting a shaft speed sensor fault in the speed sensing system when the corresponding shaft speed is not greater than the rotor speed.

16. The system of claim **15**, wherein issuing the first speed sensing system fault signal comprises issuing a rotor speed sensor fault signal responsive to detecting a rotor speed sensor fault in the speed sensing system when the corresponding shaft speed is greater than the rotor speed.

17. The system of claim **16**, wherein issuing the first speed sensing system fault comprises issuing an undetermined state signal to assign an undetermined validity state to the shaft speed sensor.

18. The system of claim **11**, wherein the rotor speed is obtained by a first controller associated with the first engine, and wherein the instructions are further executable for:

obtaining a corresponding rotor speed via a second controller associated with a second engine of the multi engine rotorcraft;

comparing the rotor speed to the corresponding rotor speed; and

issuing a rotor speed sensor fault signal responsive to determining that the rotor speed and the corresponding rotor speed differ beyond a predetermined rotor speed threshold.

19. The system of claim **11**, wherein determining whether the first engine is coupled to the at least one rotor based on the fuel flow to the first engine comprises:

adjusting the fuel flow to the first engine based on at least one ambient condition to the first engine; and

comparing the adjusted fuel flow to a predetermined fuel flow threshold;

wherein the first engine is determined to be decoupled from the at least one rotor when the adjusted fuel flow is below the predetermined fuel threshold.

20. The system of claim **11**, wherein comparing the shaft speed to the rotor speed comprises applying a scaling factor to one of the shaft speed and the rotor speed, the scaling factor based on a mechanical coupling between the first engine and the at least one rotor.

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